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QUALITATIVE EFFECTS ON SAFETY AND CONSTRUCTION MATERIALS OF 1300° F SODIUM-POTASSIUM SPRAY IN AIR AND NITROGEN

by John M. McGee and Armen S. Asadourian

Lewis Research Center
Cleveland, Ohio

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SUMMARY

An experimental investigation involving a series of five tests was conducted to learn more about the nature of sodium-potassium (NaK) fires. An understanding of such fires would aid in the protection of personnel, equipment, and facilities from injury or destruction.

Three tests were conducted in open containers with NaK spray at 1300° F in air impinging on various safety and construction materials. Two tests were conducted in closed containers, one with air and one inerted with gaseous nitrogen.

Rubber-asbestos welding-blanket material and chromated leather withstood attack best among the materials tested although no material exhibited an ultimate resistance to attack by the NaK spray. Of the construction materials tested, the 1900° F asbestos insulation material withstood attack the best, but it also did not exhibit an ultimate resistance to attack.

A small amount of smoke was produced in the inerted container from the burning of a chromated-leather glove and a face shield. Some of the smoke was also produced by NaK burning in the 2-percent residual oxygen content in the container. The chromated leather exhibited no better resistance to direct NaK spray in an inerted atmosphere.

The period of effective resistance of the plastic face-shield material currently being used was very limited in comparison with the chromated leather. Thicker face-shield material would increase its resistance time to more closely coincide with that of the resistance of chromated leather.

INTRODUCTION

Very little information is available on the nature of fires caused by the leakage of hot, pressurized sodium-potassium (NaK) into air. A better understanding of such fires

is essential if their harmful effects on personnel, test equipment, and facilities are to be minimized.

Prior to this investigation liquid-metal fire tests were performed by the Mine Safety Appliances Research Corporation for the United States Air Force (ref. 1). This work was limited to preemission temperatures less than 700° F and mostly to liquid metals other than NaK. The Argonne National Laboratory initiated data compilations (ref. 2) that led to the publishing of the Liquid Metals Handbook (ref. 3). The handbook contains results of tests run on safety materials in NaK at 1022° F but not with NaK burning in air.

To obtain more data on NaK fires in air, a series of five tests was conducted at the Lewis Research Center. The nominal NaK preemission condition was 1300° F at 60 pounds per square inch absolute pressure. In three of the tests, NaK was sprayed on various safety and construction materials in an open box. The last two tests were conducted inside closed boxes, one of which was inerted with gaseous nitrogen prior to NaK injection. The investigation was carried out in boxes of the same size with the injection of NaK at approximately 1300° F under similar weather conditions.

The information obtained from the tests has been applied to the design of NaK fire-protection systems at the Lewis Research Center.

It was not originally intended to publish the results of this investigation; therefore, the investigation was not carried out in the systematic manner normally found in reported work. However, because of the very limited information available in the literature on NaK fires, it was felt that the report should be published to supply useful information to groups handling NaK or other alkaline metals.

A motion-picture film supplement that illustrates the results has been prepared and is available on loan. A request card and a description of the film are included at the back of this report.

APPARATUS AND INSTRUMENTATION

A remote area was chosen as the site for the experiments to minimize the hazards to personnel in the surrounding areas. The layout, shown in figure 1, was designed to utilize the prevailing winds to carry the caustic smoke away from the operating personnel and instrumentation during the testing period.

A schematic drawing of the NaK injection rig is shown in figure 2. The rig contained a NaK injection tank that was 2 feet long and 10 inches in diameter. The outside of the tank was provided with strip heaters. High-temperature asbestos thermal insulation covered the tank and heaters. An argon pressurization system was provided to ensure a constant pressure of 60 pounds per square inch absolute above the surface of the NaK during injection. The top of the tank was provided with an inlet and vent to allow for

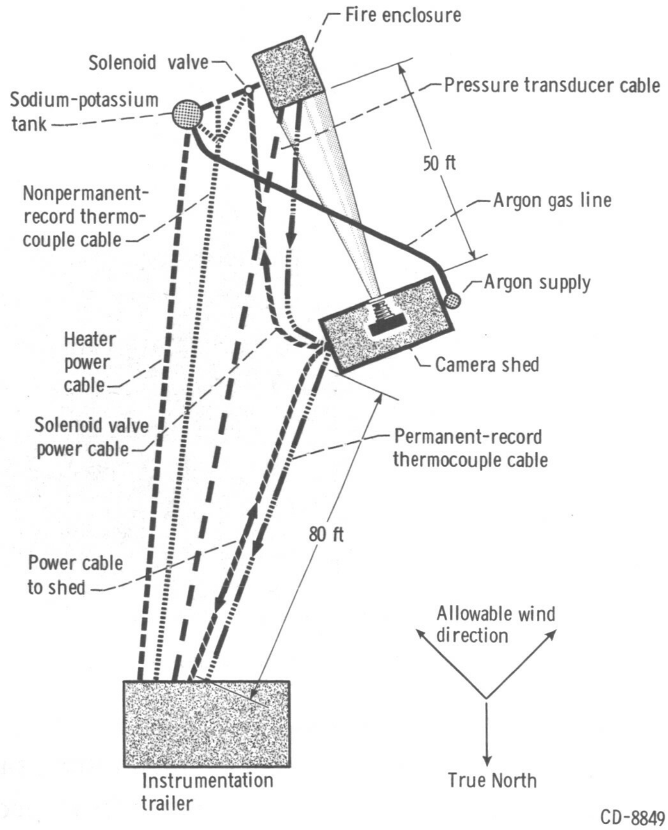


Figure 1. - General layout of apparatus for sodium-potassium fire test. Camera and solenoid-valve on-off controls are located inside shed.

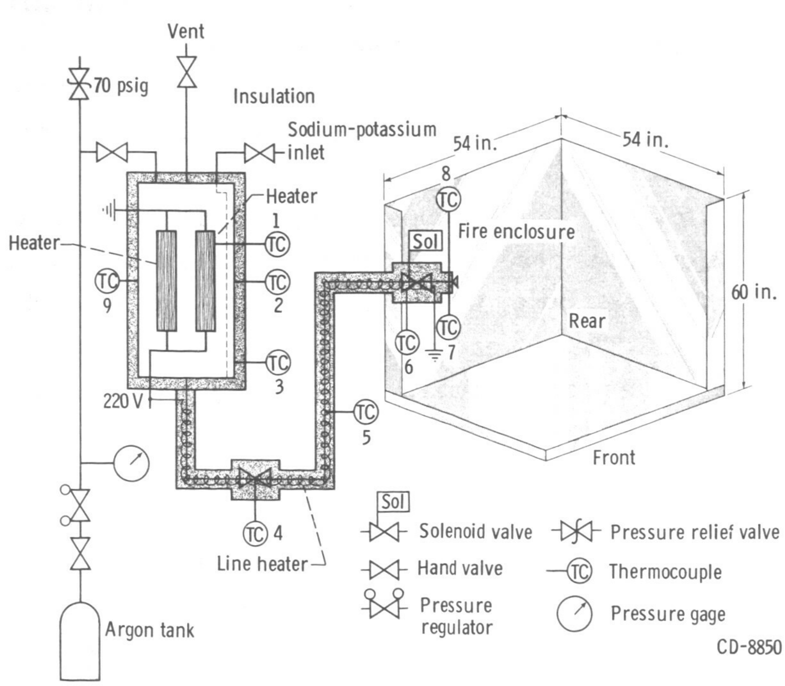


Figure 2. - Schematic drawing of injection rig.

Figure 3. - Sodium-potassium fire-test apparatus before test 5.

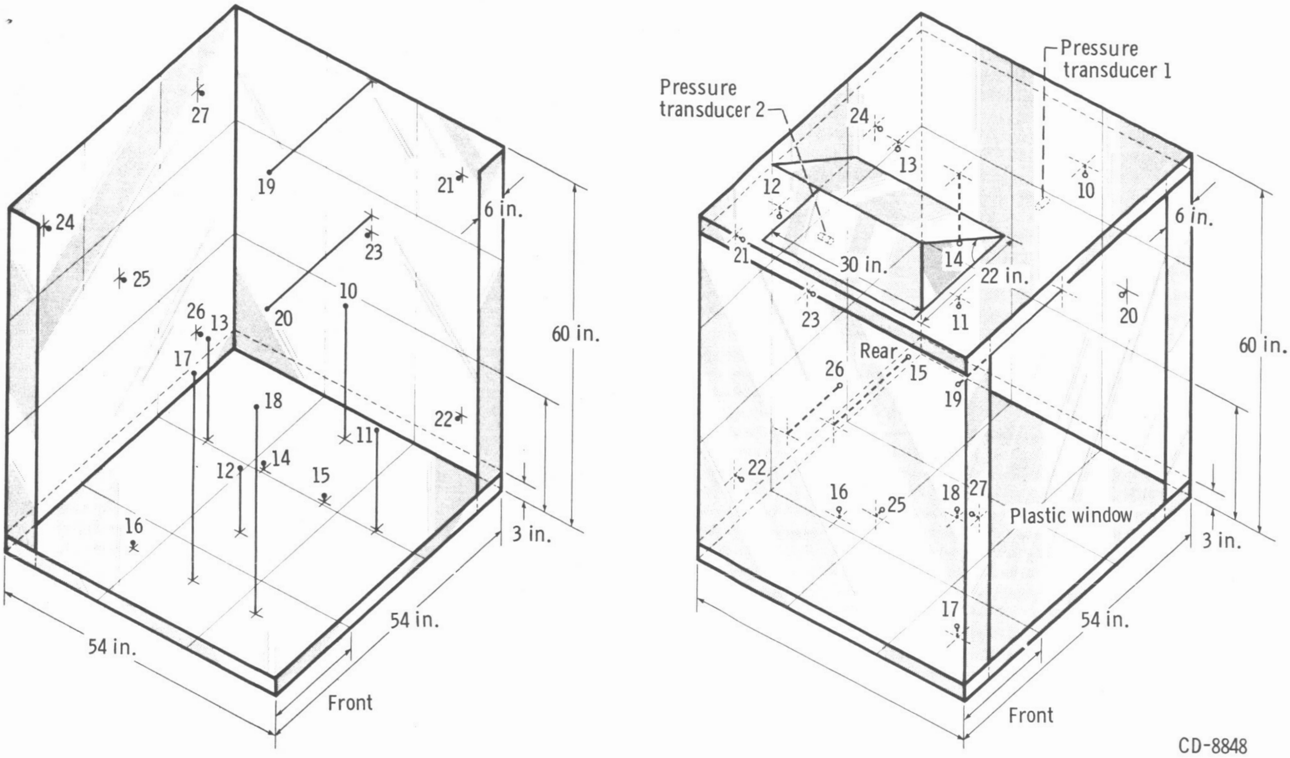
transferal of NaK to the tank under inert gas conditions.

The NaK was fed to the outlet nozzle through 3/8-inch tubing that was both heated and insulated. One hand valve was included at the tank outlet to provide for a positive shutoff during the heating of the NaK. An on-off, gas-operated, solenoid-controlled valve was installed upstream of the nozzle to provide for remote starting and stopping of NaK injection. The nozzle used was simply a flattened tube with its direction adjusted to spread a stream of NaK over the rack of sample materials.

The open fire-containment boxes were designed to catch most of the NaK spray and to allow for visual observation. Open boxes were used in the first three tests, and a new box was used for each test.

The closed boxes were completely enclosed but were not constructed to be leak tight. Leak-tight containers were considered to be too hazardous and a poor simulation of a real facility. One side of the closed boxes was constructed of a transparent plastic material and faced the camera shed. The closed boxes were provided with a blowout door at the top that was weighted to relieve at the maximum allowable pressure of 0.5 pound per square inch. Figure 3 shows the closed box and the equipment used for test 5. With the exception of the closed box and top-mounted camera, this setup is typical of the appratus used for all the tests.

The camera shed was located 50 feet from the injection rig and was set to face the fire containment boxes. Color motion pictures were used for all the tests with film speeds of 24, 48, 100, and 500 frames per second. These films, when projected at a normal 24 frames per second, correspondingly show events happening at 1, 2, 4, and



(a) Open-box tests 1 to 3. (b) Closed-box tests 4 and 5.

Figure 4. - Fire containment boxes for sodium-potassium fire test. Container wall material, 3/16-inch-thick steelplate. (Numbers denote location of thermocouples.)

20 times slower than normal.

The camera shed was used as the control point for the testing. A time sequence system was set up in the shed to turn on the cameras 2 seconds before the solenoid valve was opened. This 2-second period was required to allow the cameras to attain proper speed. The electrical signal that opened the solenoid valve was recorded both as a photoflash on film and as a trace on an oscillograph.

Figure 2 shows the location of the rig thermocouples monitored on a thermocouple galvanometer prior to NaK emission. Thermocouples were also installed in the test boxes (fig. 4) to give some indication of the local fire temperatures. Pressure transducers were installed to measure box pressure on the closed tests (fig. 4(b)).

PROCEDURE

Table I lists several pretest conditions for each test. In all cases, the data presented were recorded within a 2-minute period prior to NaK injection. The weather conditions listed did not vary significantly between tests. To permit adequate observation and

TABLE I. - PRETEST INFORMATION AND CONDITIONS

FOR SODIUM-POTASSIUM FIRE TESTS

Test	Ambient temper-ature, $^{\circ}F$	Baro-metric pres-sure, in. Hg	Relative humidity, percent	Wind direc-tion, deg from true North	Wind veloc-ity, knots	Temperature, $^{\circ}F$								
						Heater	Sodium-potassium tank middle	Sodium-potassium tank bottom	Hand valve	Emis-sion tube	Sole-noid valve	Nozzle		Sodium-potassium tank
						Thermocouple								
						1	2	3	4	5	6	7	8	9
Open-box test														
1	42	29.40	53	300	14	1225	1275	1180	400	1240	380	1300	1300	1380
2	50	29.50	58	260	14	1260	1290	1190	440	1250	400	1290	1200	1380
3	47	29.67	58	350	8	1300	1340	1200	480	1160	440	1250	1430	1385
Closed-box test with air														
4	39	29.46	62	0	9	1270	1310	1200	560	1230	440	----	----	----
Closed-box inerted with nitrogen														
5	40	-----	--	---	--	920	1000	840	460	940	380	----	----	----

photography of the open-box test, a wind speed of 5 to 15 knots and a direction of 215° to 45° were necessary. These conditions assured that the forward half of the boxes were visible during most of the testing period.

Tests 1, 2, and 3 were run in open boxes, with NaK injected at approximately 1300° F in each case. The sample materials selected for tests 1 and 3 included a variety of personnel-protection equipment, and those selected for test 2 included insulation, sealing, and instrumentation materials used in the construction of facilities.

Test 4 was run in a closed box filled with air. No sample materials were used. The spray nozzle used in the previous test was omitted, and the NaK was injected at a temperature of 1300° F to duplicate a solid-stream NaK leak. Calculations were made to ensure that enough NaK was injected so that the oxygen content would be lowered as far as the reaction would permit.

Test 5 was run in a closed box containing an atmosphere of 2 percent oxygen and 98 percent nitrogen. The box was sealed with tape for this test to prevent oxygen from diffusing in. Also, the nitrogen inlet flow was continued during the test to provide a slight positive pressure. The NaK was injected at 1000° F instead of 1300° F as in test 4. A face shield and two chromated-leather gloves were used as sample materials in this test.

RESULTS AND DISCUSSION

Table II lists the maximum temperatures recorded during the tests and, for tests 4 and 5, the maximum pressure achieved. Some of the maximum temperatures are actually the final temperatures reached before the thermocouples malfunctioned. These temperatures are coded accordingly.

Test 1

A false start occurred prior to test 1, and the flashbulb was prematurely flashed. Also, only the 48-frame-per-second color-film camera recorded the burning. As indicated in table II, all thermocouples operated properly.

During test 1, the spray was too high and impinged on the back of the sample rack. Therefore, the samples received only splatters of NaK. Photographs taken before and after the test (fig. 5) indicated that the rubber-asbestos welding blanket withstood the NaK spray better than the other materials shown, with the exception of the neoprene hose. Next best in resistance to attack was a plastic-covered cloth and following that a double thickness of flameproof cotton cloth.

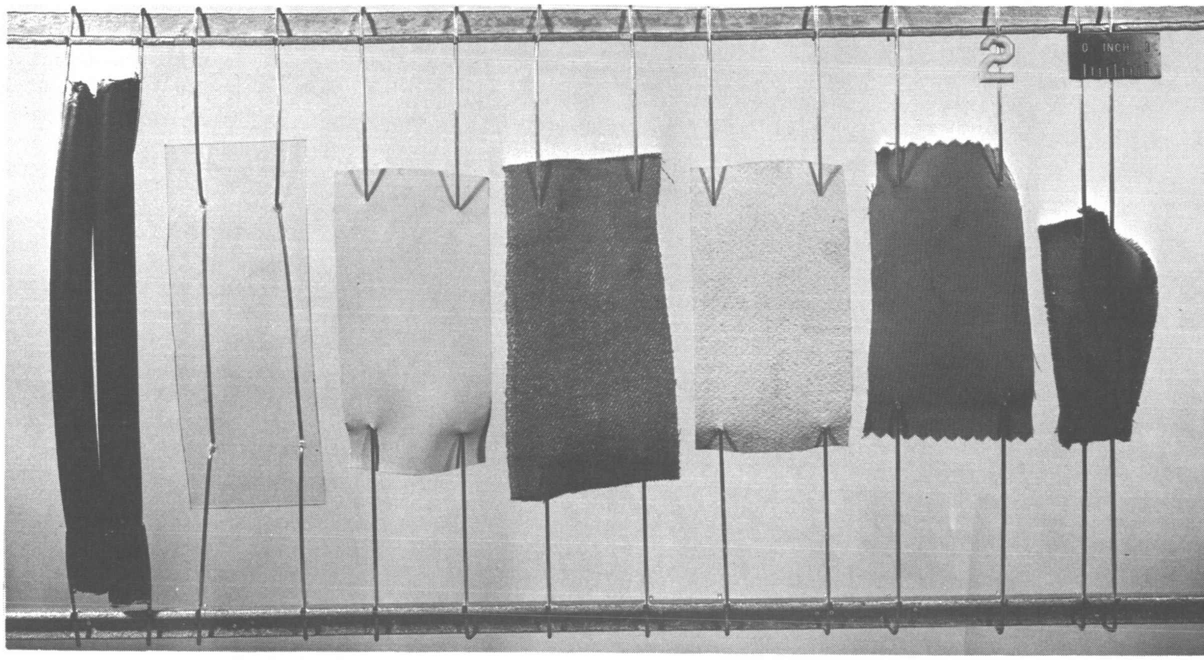
TABLE II. - MAXIMUM TEMPERATURES AND PRESSURES

DURING SODIUM-POTASSIUM FIRE TESTS

Open-box test			Closed-box test	
			Air	Nitrogen
1	2	3	4	5
Sodium-potassium flow rate, lb/hr				
487	487	487	(a)	487
Sodium-potassium flow time, sec				
91	91	91	(a)	64
Quantity of sodium-potassium discharged, lb				
12.3	12.3	12.3	8.6	8.6

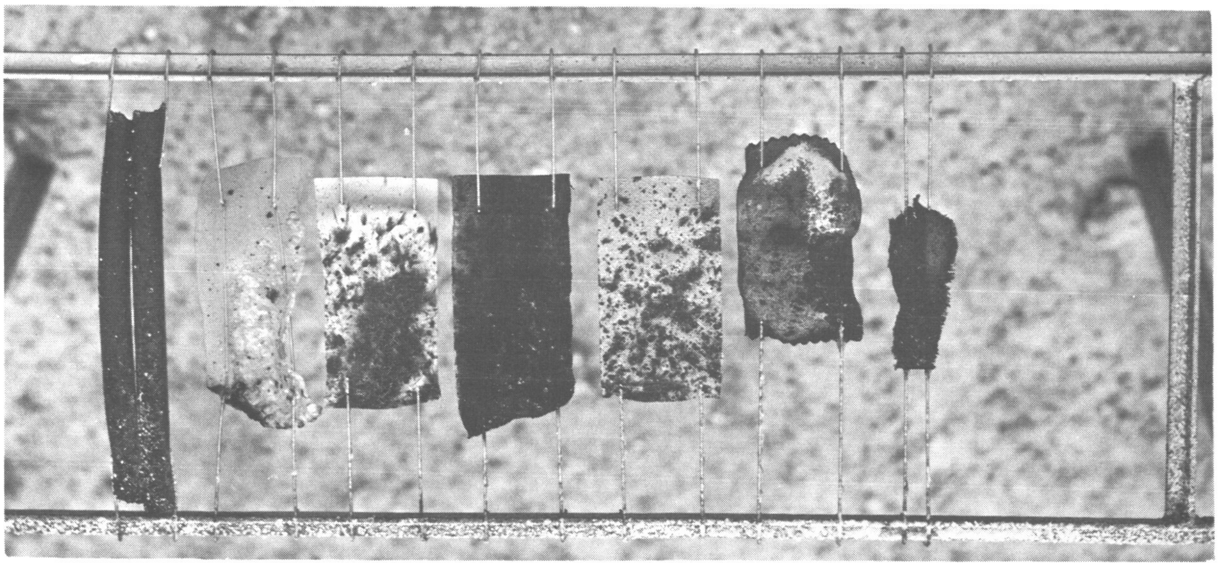
Thermocouple	Open-box test						Closed-box test			
							Air		Nitrogen	
	1		[b]2		3		4		5	
	Temperature, °F	Time, sec	Temperature, °F	Time, sec	Temperature, °F	Time, sec	Temperature, °F	Time, sec	Temperature, °F	Time, sec
10	1350	25	--------	-----	375	91	[c]345	34	225	30
11	290	79	--------	-----	285	90	[c]160	20	235	26
12	250	44	--------	-----	1475	37	[c]225	34	255	22
13	490	77	--------	-----	805	36	[c]235	34	170	24
14	1170	17	--------	-----	1610	66	(d)	---	260	48
15	350	107	--------	-----	1080	6	(d)	---	530	33
16	175	44	--------	-----	275	36	(d)	---	225	64
17	1830	92	--------	-----	190	12	(d)	---	250	33
18	105	92	--------	-----	90	12	[c]245	39	410	67
19	215	68	--------	-----	275	11	[c]455	91	350	51
20	215	75	--------	-----	485	12	325	106	250	35
21	540	17	--------	-----	195	92	(d)	---	235	21
22	1740	123	--------	-----	620	91	(d)	---	180	67
23	900	15	--------	-----	170	70	(d)	---	140	35
24	365	83	--------	-----	160	97	[c]235	23	210	26
25	655	8	--------	-----	150	70	[c]250	36	160	26
26	205	94	--------	-----	500	93	----	---	---	--
27	140	92	--------	-----	175	94	----	---	---	--
Pressure transducer							Pressure, in. H_2O	Time, sec	Pressure, in. H_2O	Time, sec
1	----	---	--------	-----	----	--	1.26	27	(e)	--
2	----	---	--------	-----	----	--	1.50	27	(e)	--

[a]Unknown.
[b]Thermocouple failed after cable was destroyed by sodium-potassium spray.
[c]Thermocouple malfunctioned at some later time.
[d]Malfunction.
[e]Negligible.



Neoprene air hose | Plastic face shield | Plastic-covered cloth | Heavy flame-proof cotton | Rubber-asbestos welding blanket | Cotton neck liner | Thin flame-proof cotton

(a) Before test.

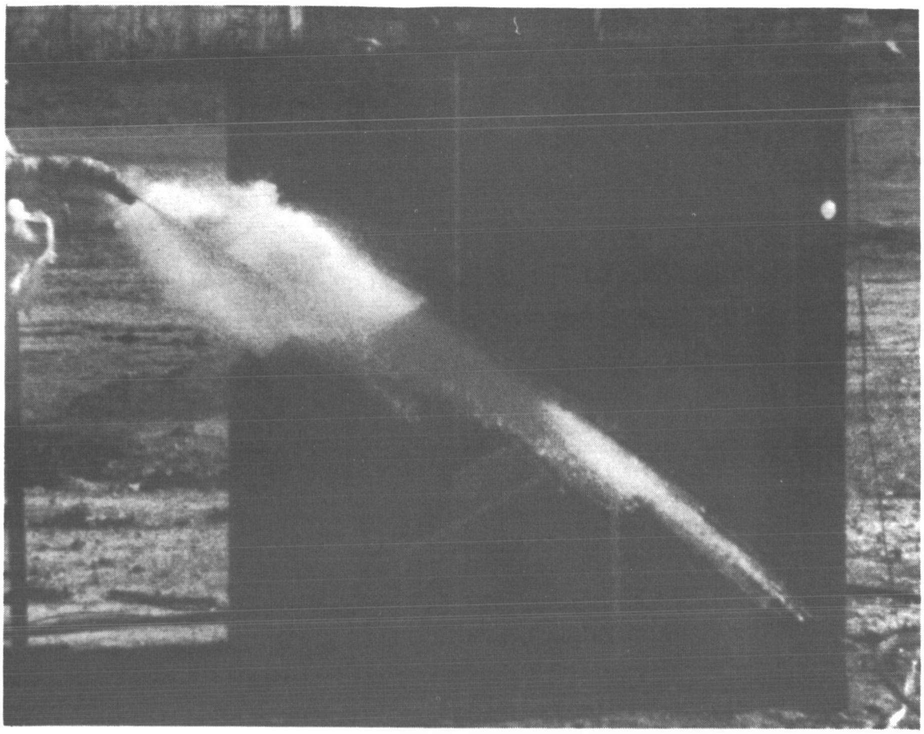


Neoprene air hose | Plastic face shield | Plastic-covered cloth | Heavy flame-proof cotton | Rubber-asbestos welding blanket | Cotton neck liner | Thin flame-proof cotton

(b) After test.

Figure 5. - Sodium-potassium fire test 1. Test samples, safety-clothing materials.

The plastic face-shield material, the face-shield neck-liner cotton cloth, and the single thickness of flameproof cotton cloth all withstood attack poorly. It is significant that the plastic face shield was damaged severely although it apparently received only a small quantity of NaK.



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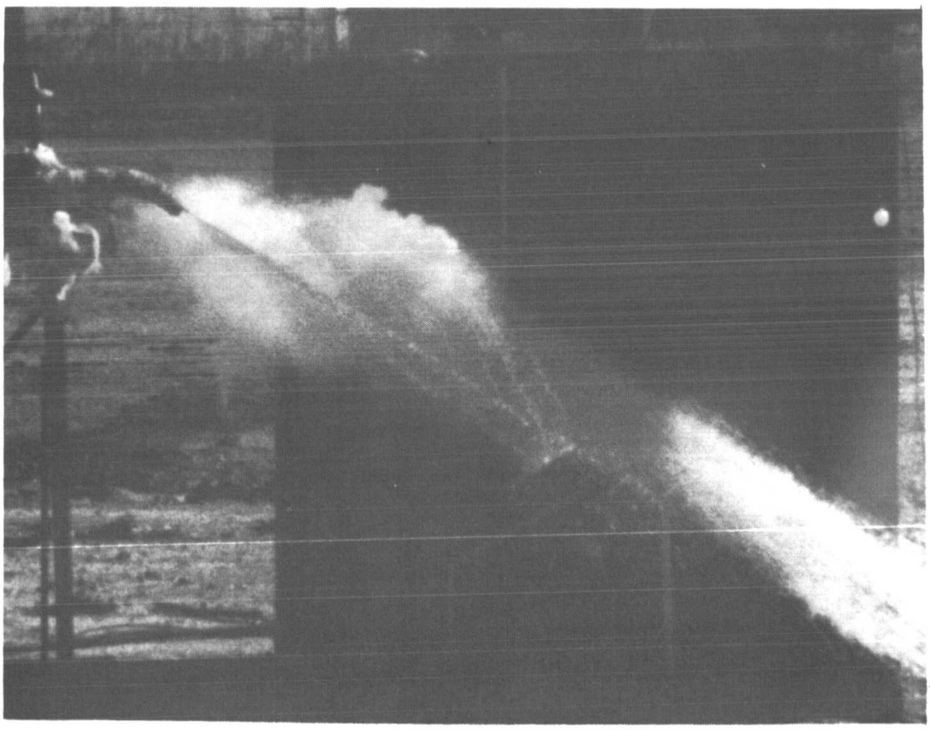

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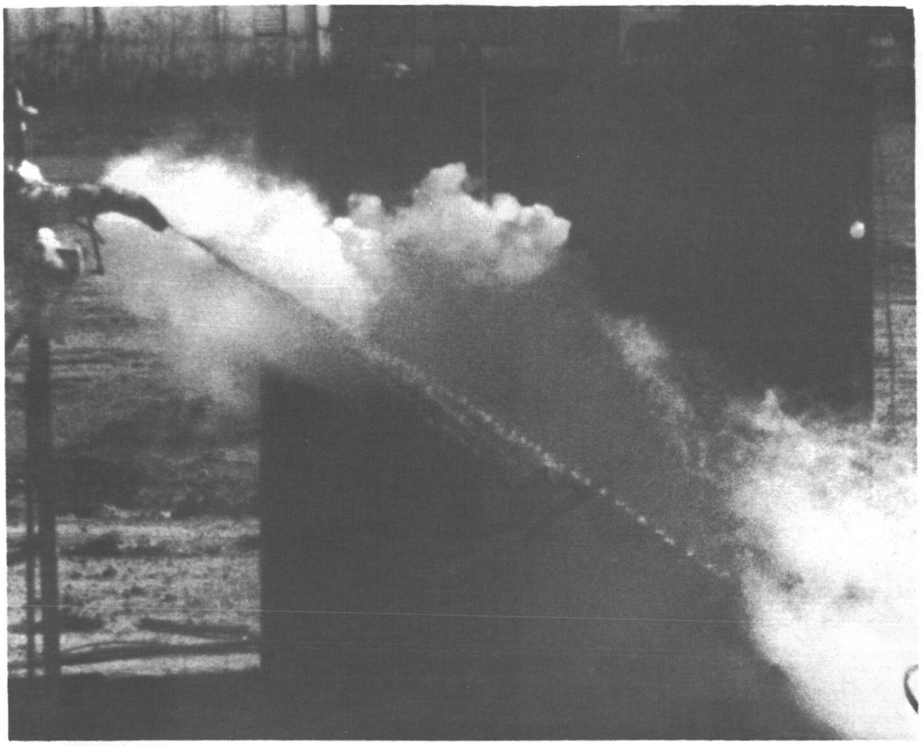
Figure 6. - Sodium-potassium spraying outside box and striking thermocouple cable during test 2.



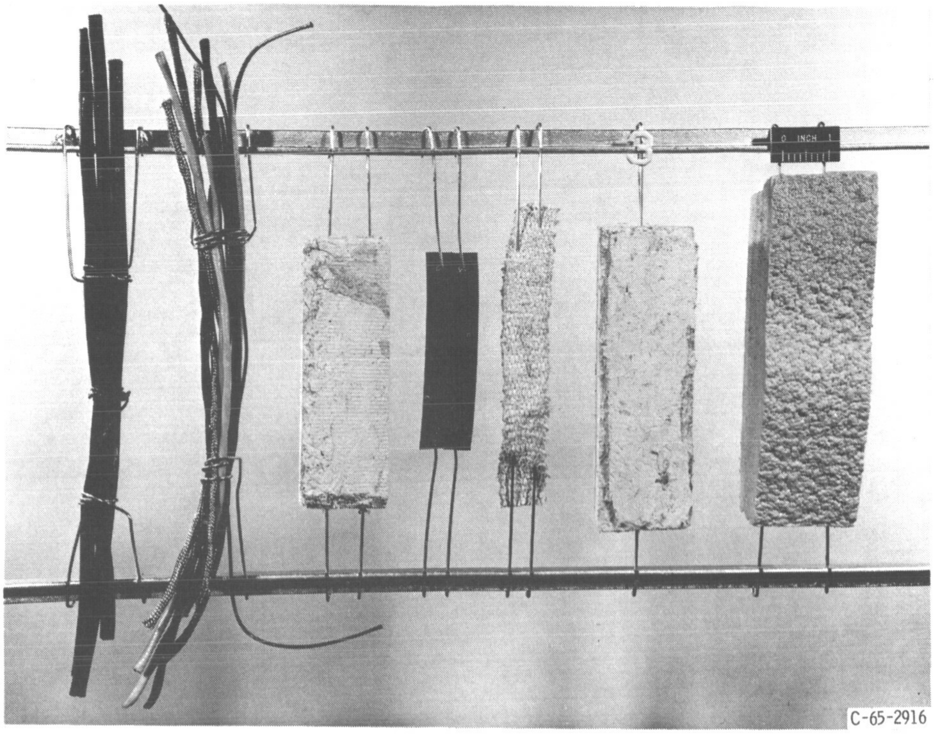
0.42 sec

Figure 6. - Concluded.

Test 2

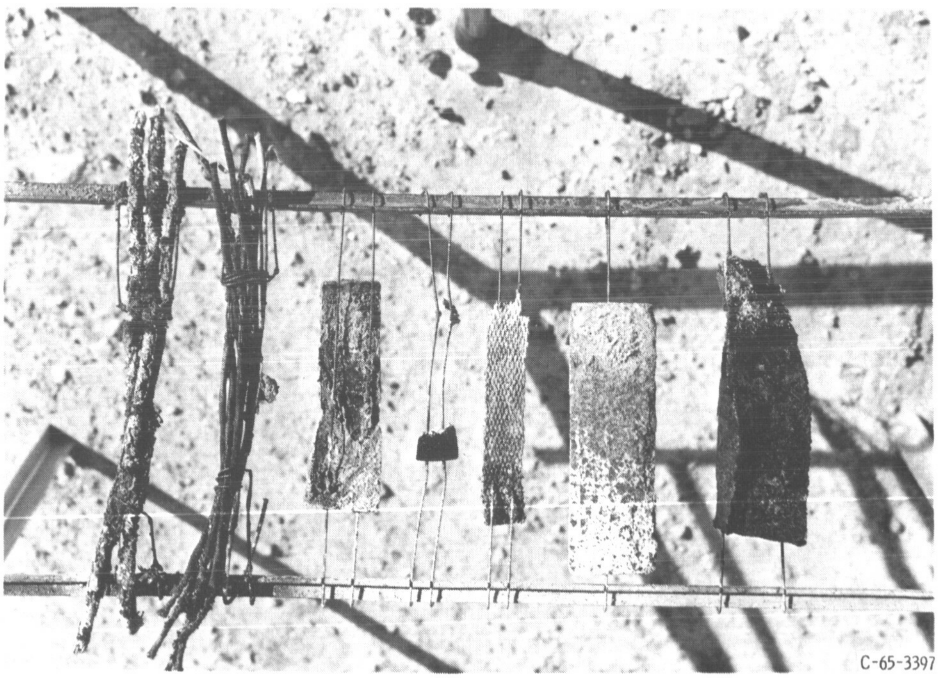
In test 2 the NaK stream first sprayed outside the box, but, for the remaining injection time, it sprayed inside the containment box (see fig. 6). It is interesting to note that the portion of the NaK spray that missed the box destroyed the thermocouple cable, and, as a result, all the test thermocouples malfunctioned.

Some of the samples (fig. 7) were sprayed directly, and the others only partially. The low-temperature asbestos cloth seemed to withstand the spray, but it is doubtful that it received a sustained spray for any appreciable length of time. The only samples that received a direct spray and had good resistance to attack were the 1900° F asbestos insulation and the metal braid thermocouple wire. The rubber sheet material shown in figure 7 was almost eradicated.



Rubber transducer cable — Metal-polytetrafluoroethylene thermocouple — Asbestos 1600° F insulation — Rubber sheet — Asbestos cloth insulation — Asbestos 1900° F insulation — Urethane rigid foam

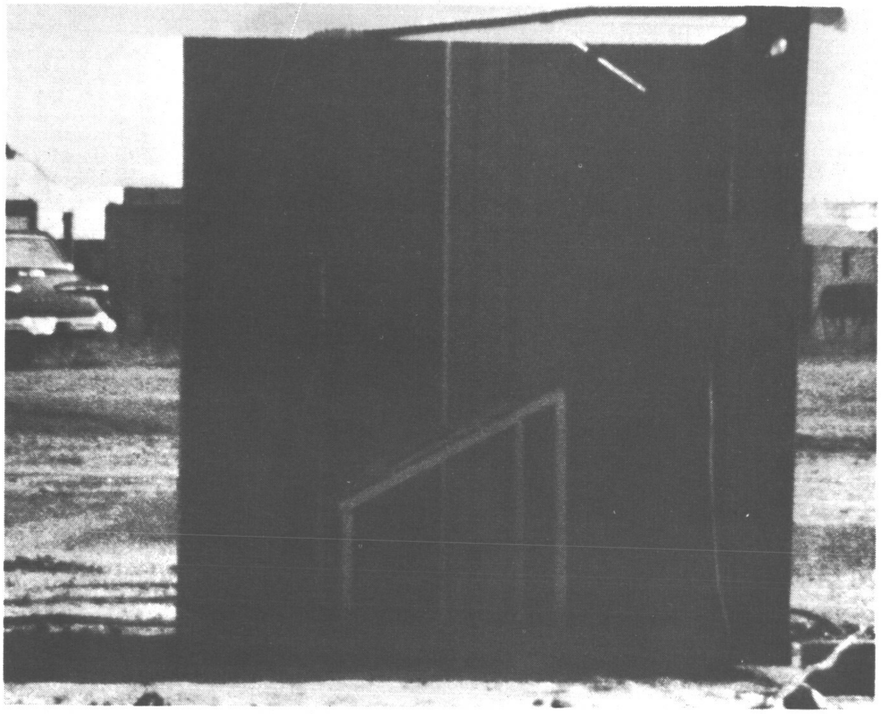
(a) Before test.



Rubber transducer cable — Metal-polytetrafluoroethylene thermocouple — Asbestos 1600° F insulation — Rubber sheet — Asbestos cloth insulation — Asbestos 1900° F insulation — Urethane rigid foam

(b) After test.

Figure 7. - Sodium potassium fire test 2. Test samples, insulation, sealing, and instrumentation materials.



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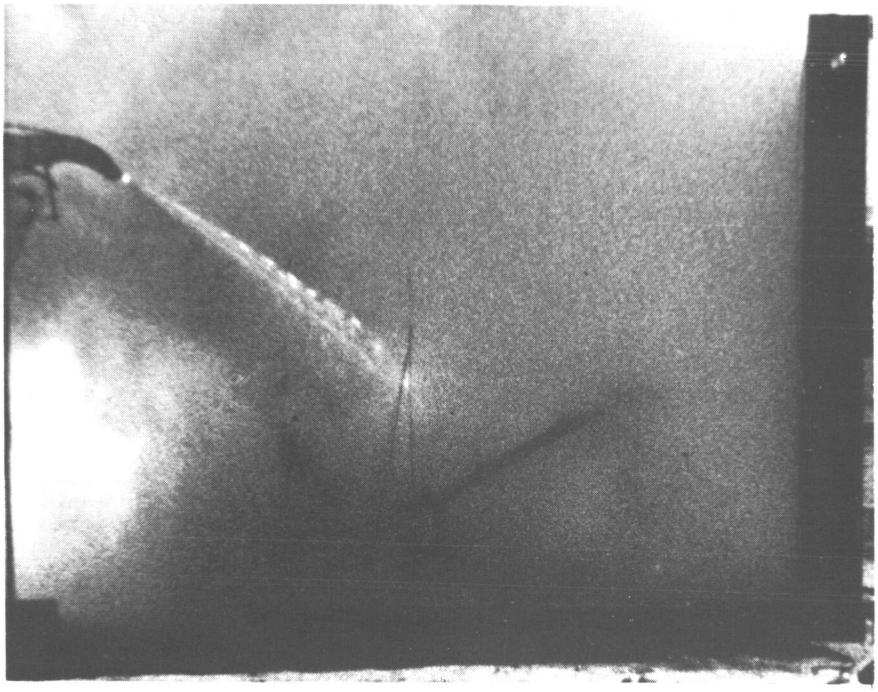

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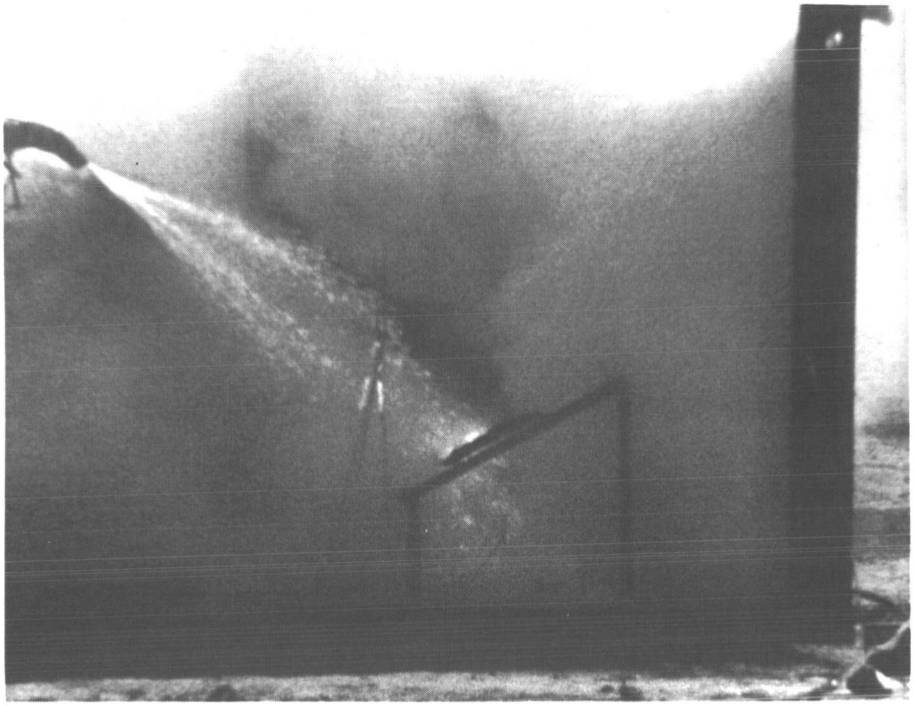
Figure 8. - Ninety-five-second period of sodium-potassium spray during test 3.



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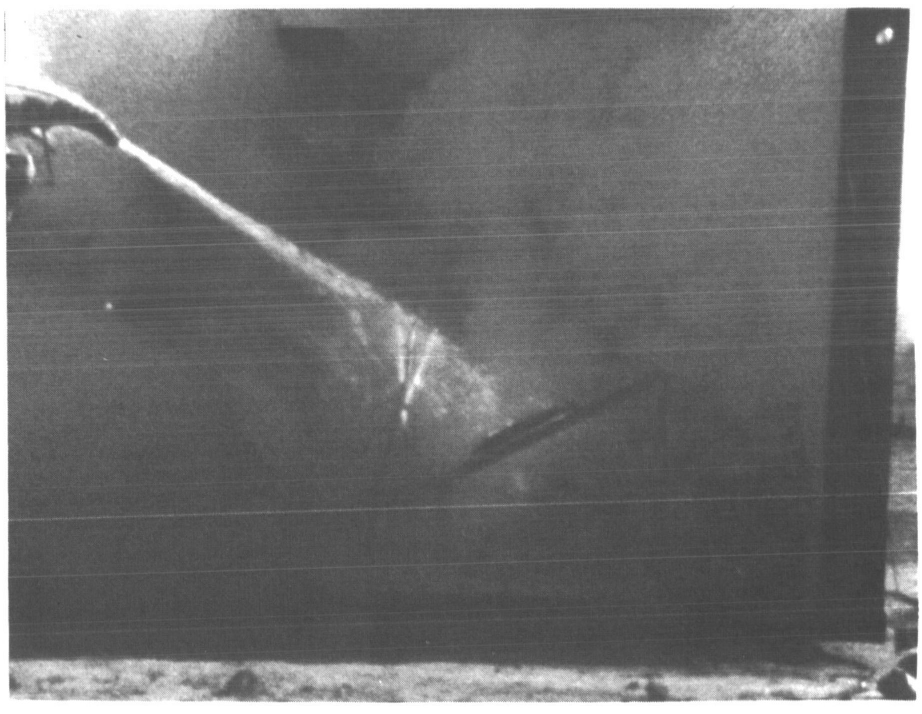

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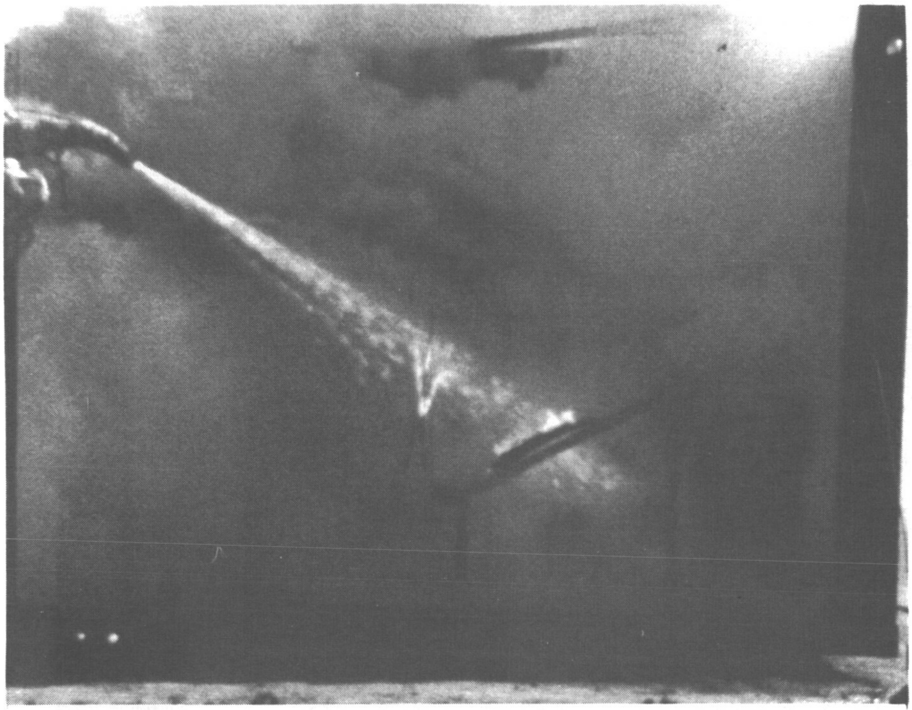
Figure 8. - Continued.



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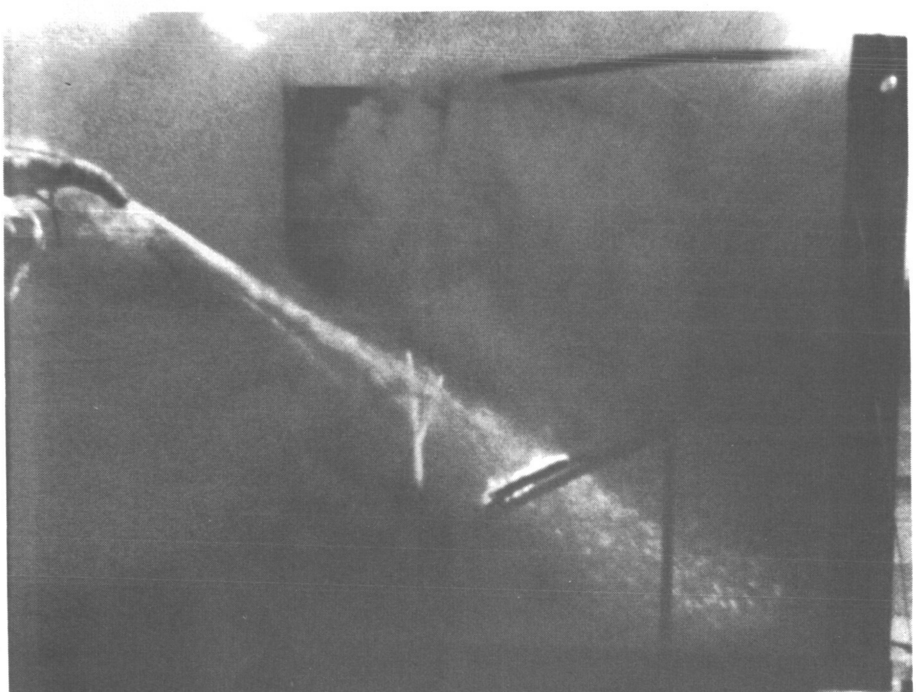
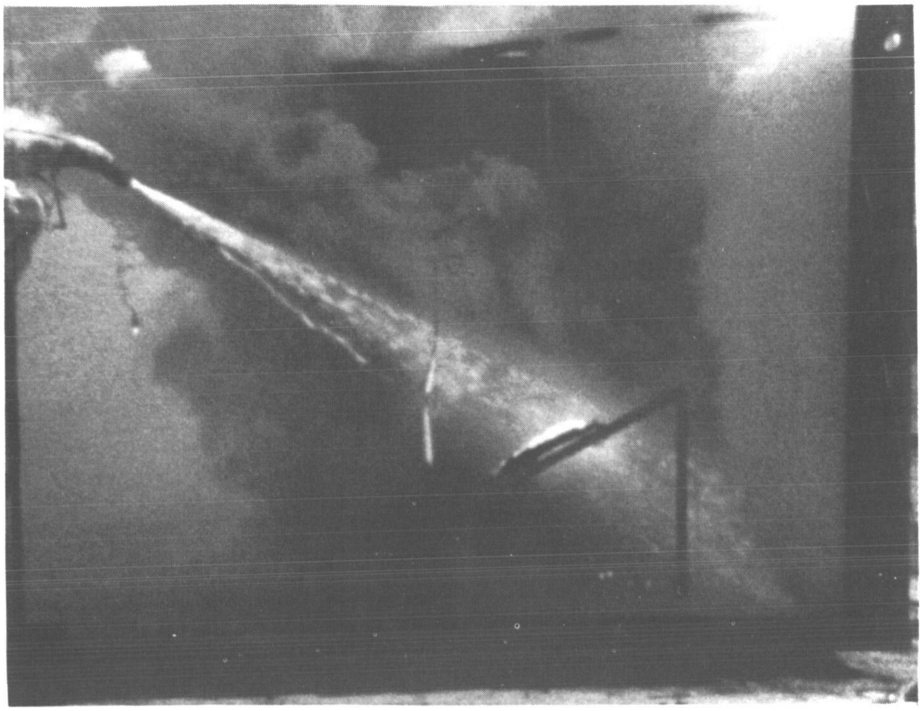
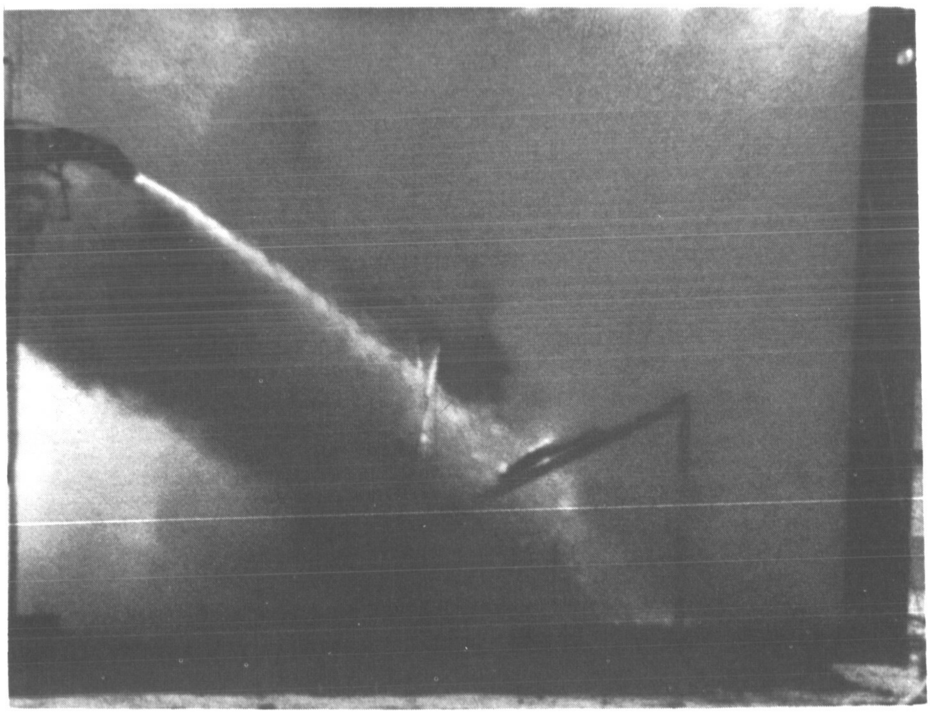


50 sec

Figure 8. - Continued.

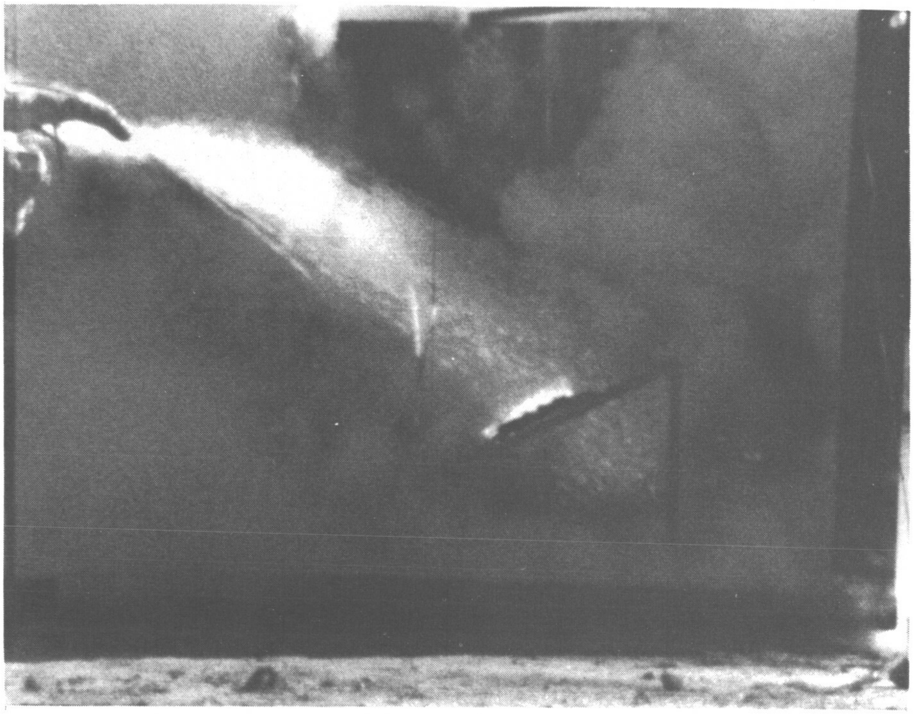


60 sec



70 sec

Figure 8. - Continued.



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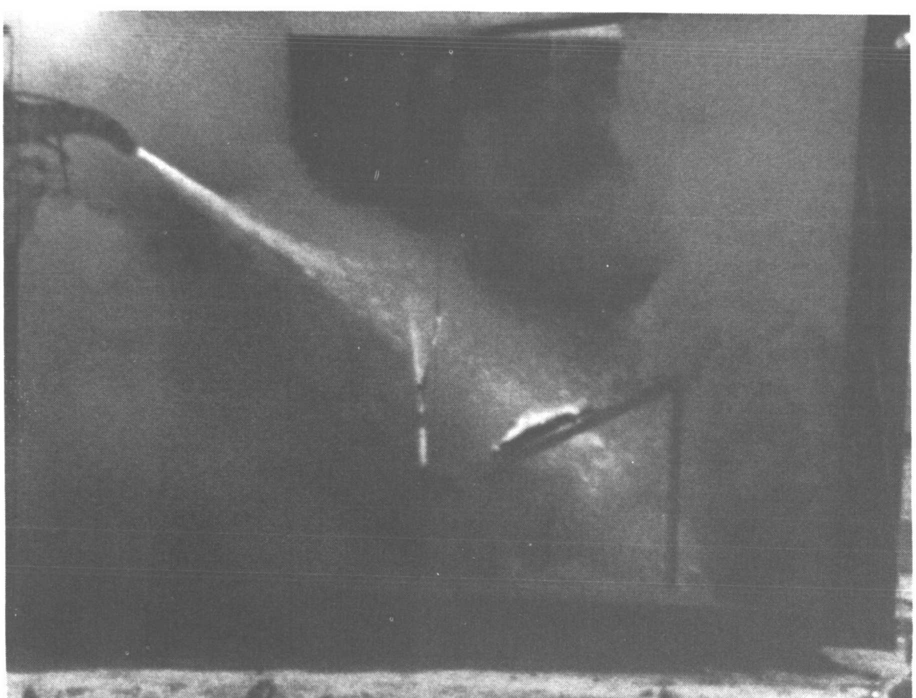
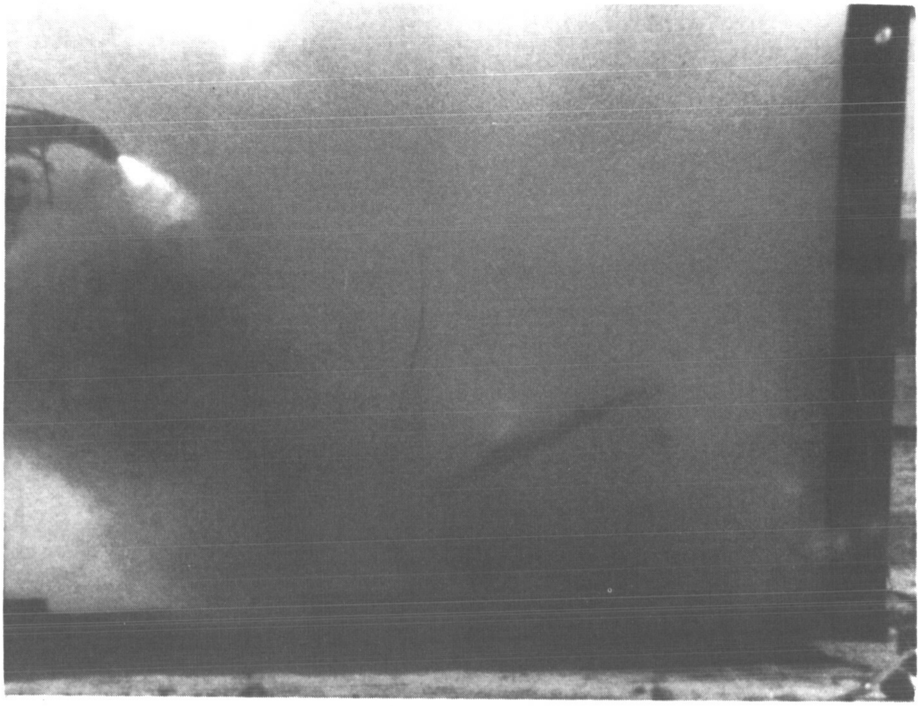


90 sec

Figure 8. - Continued.



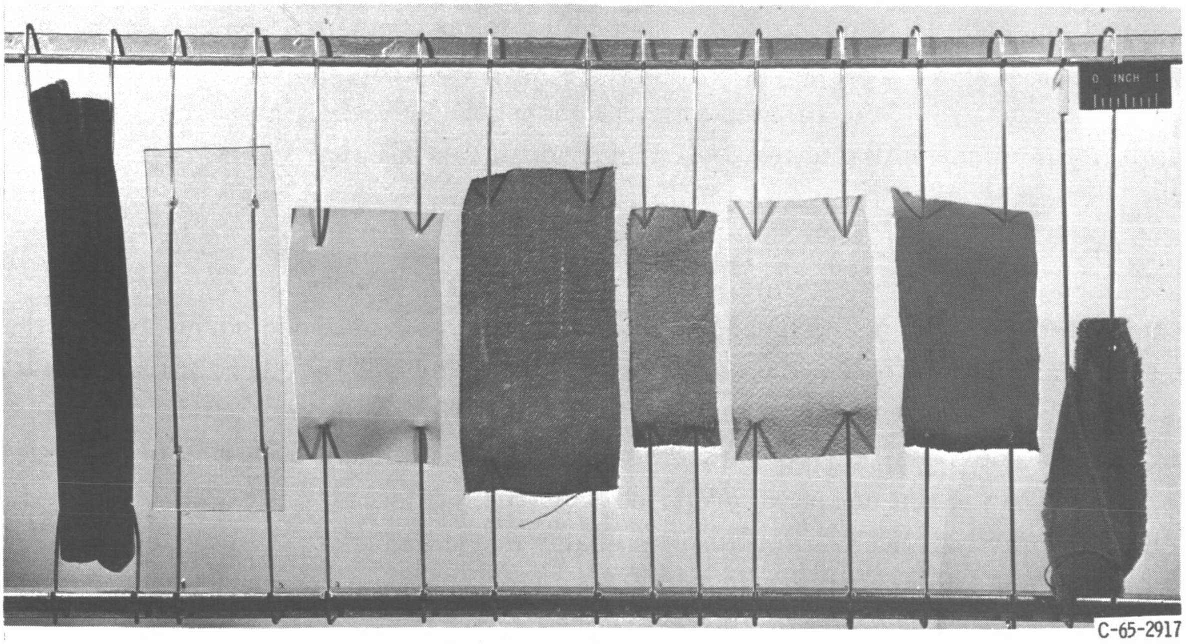
95 sec
Figure 8. - Concluded.

Test 3

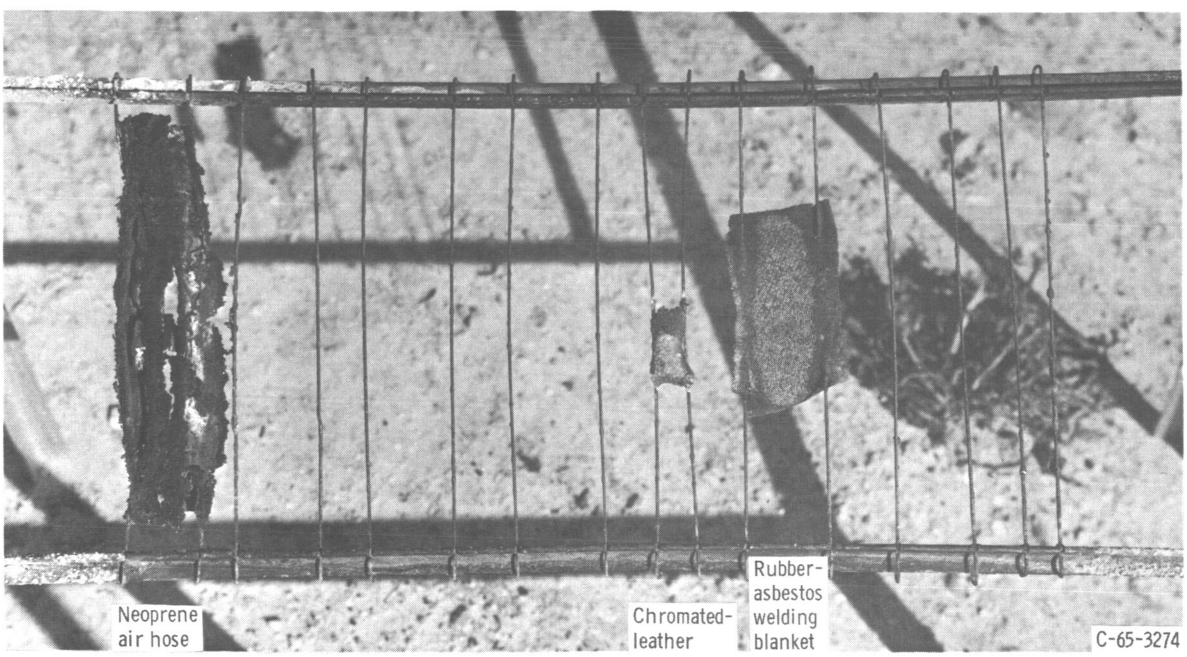
Test 3 ran successfully with all cameras operating normally (24, 48, 100, and 500 frames per second). The samples were hit directly by the spray, and all thermocouples functioned normally. Figure 8 shows a sequence of photos covering the total period of NaK injection.

Photographic evidence indicates that any thermocouple receiving a direct spray of NaK for 4 or 5 seconds would achieve a maximum temperature above 1400° F. Temperatures of 500° to 1400° F were recorded by thermocouples receiving NaK sprays of shorter duration or intermittent droplets. The maximum temperature within the NaK smoke was approximately 500° F; however, thermocouples that were in close proximity to smoke or NaK spray but not in direct contact with either did not indicate temperatures exceeding 105° F.

The samples in test 3 (fig. 9) were hit so directly that the only basis for comparison was whether or not the sample was completely eradicated. The three samples left after test 3 were neoprene rubber hose, chromated leather (not used in test 1), and the rubber asbestos welding blanket. The welding blanket was discolored and charred, but it was not penetrated and retained some consistency. The chromated leather was almost completely charred and crumbled easily. The neoprene rubber remained, probably because it was a thick sample, but it was penetrated and heavily charred.



(a) Before test.



(b) After test.

Figure 9. - Sodium-potassium fire test 3. Test samples, safety-clothing materials.

Test 4

In test 4, the first closed test with air, smoke began to fill the box immediately after NaK injection, and visual observation was limited to observing the smoke coming out of the seams and trapdoor. No sample materials were used for this test, and all cameras functioned normally. This test was a good demonstration of the almost immediate loss of visibility in an unventilated test cell with a normal initial air content.

Test 5

During test 5, the closed inert box test, all cameras functioned normally, but the NaK spray failed to hit one of the chromated-leather gloves. Five seconds into the test the smoke inside the fire containment box began to limit visual observation. The smoke came from two sources: the hot NaK stream and the reaction of NaK with the sample materials. The amount of smoke produced from the NaK spray was small compared with a NaK spray burning in air but was probably dense enough to be detected by a smoke-detection device. Figure 10 is a comparison of smoke conditions between tests 4 and 5 at the indicated time intervals.

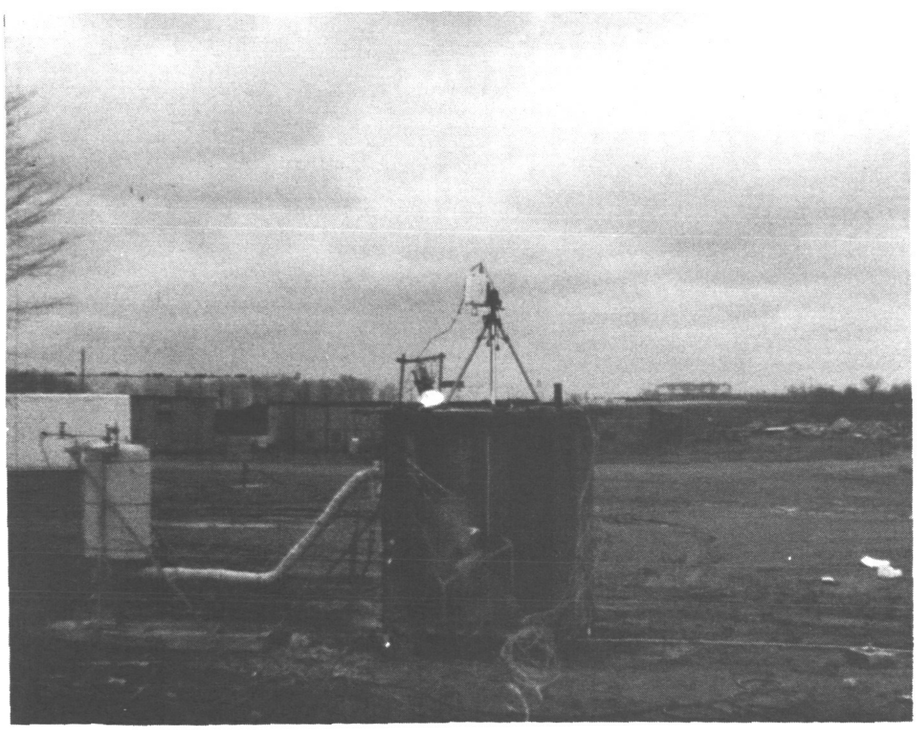
One glove that received NaK spray was completely eradicated, and the face shield had only metal parts remaining. These metal parts and the second glove, which did not receive direct NaK spray, survived the test and is shown in figure 11.

CONCLUDING REMARKS

None of the materials tested displayed a longterm resistance to a NaK spray at 1300° F. The results of test 5 indicated that resistance of chromated leather or face-shield plastic to NaK spray is not greatly increased by inerting to 2 percent oxygen. Of all the samples tested, the welding blanket material had the best resistance to attack, and the chromated leather exhibited the best resistance of the materials currently being used as clothing. Since transparent face-shield materials are usually either silicon based or hydrocarbon based, probably no face-shield material exists with good resistance to NaK spray. The thickness of face-shield material now being used provides for a protection time far less than that for chromated leather. A thicker face-shield material, while providing no ultimate protection, would increase the time of penetration of a NaK spray.

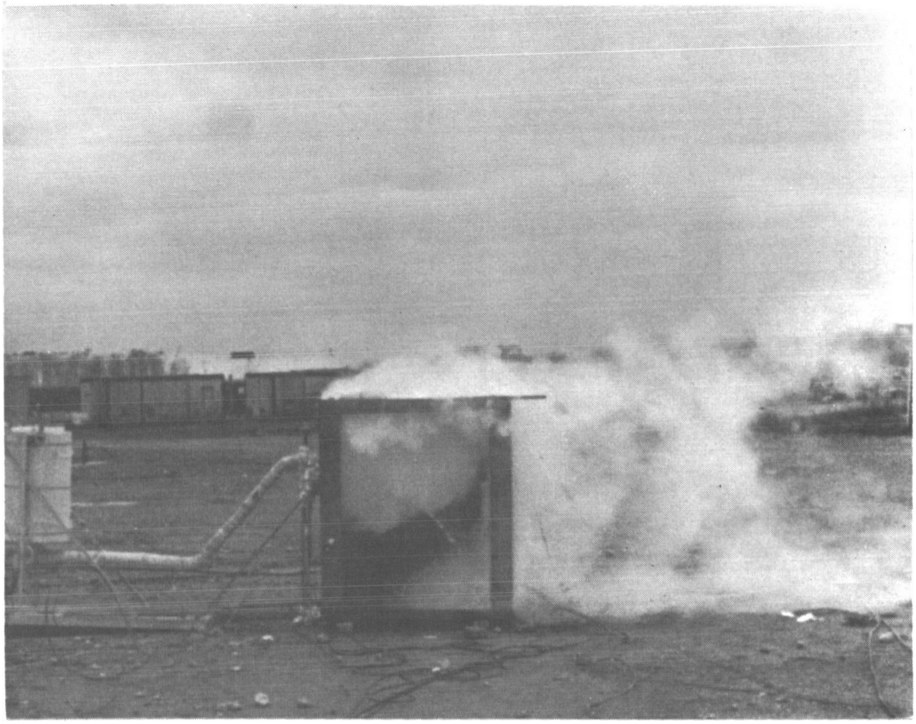
Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, November 18, 1966,
701-04-00-02-22.

Test 4; 1 sec

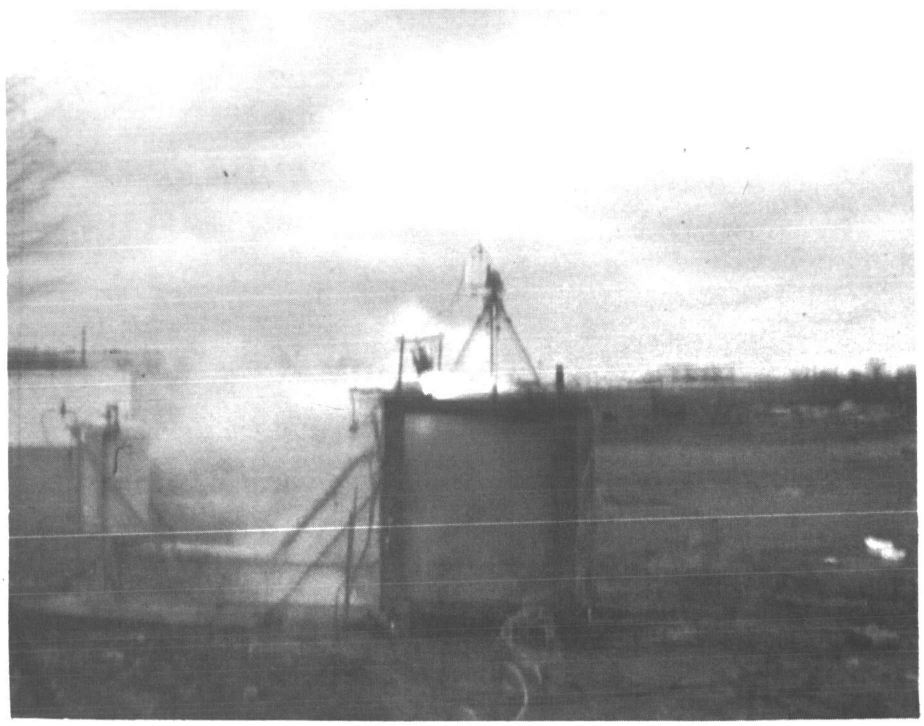


Test 5; 1 sec

Figure 10. - Comparison of smoke conditions for sodium-potassium fire tests 4 and 5.



Test 4; 5 sec



Test 5; 5 sec

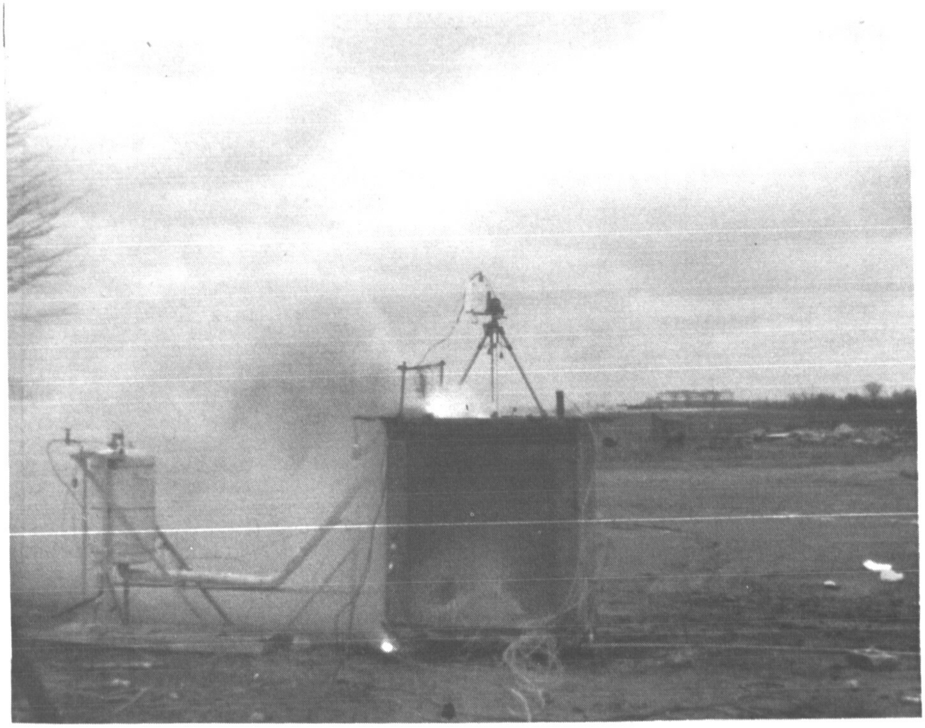
Figure 10. - Continued.

Test 4; 10 sec

Test 5; 10 sec

Figure 10. - Continued.

Test 4; 20 sec



Test 5; 20 sec

Figure 10. - Concluded.

Figure 11. - Safety-clothing materials after sodium-potassium fire test 5.

REFERENCES

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